Methodology of ECA material characterization and qualification

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Electrically Conductive Adhesive

- Low temperature interconnection solution compatible with perovskite material
- Lead, Bismuth, Indium free

Understanding the mechanical and electrical behaviour to assess the failure mechanism

Methodology

1. **Process development**
    1. Differential Scanning Calorimetry (DSC)
    2. Rheological behaviour

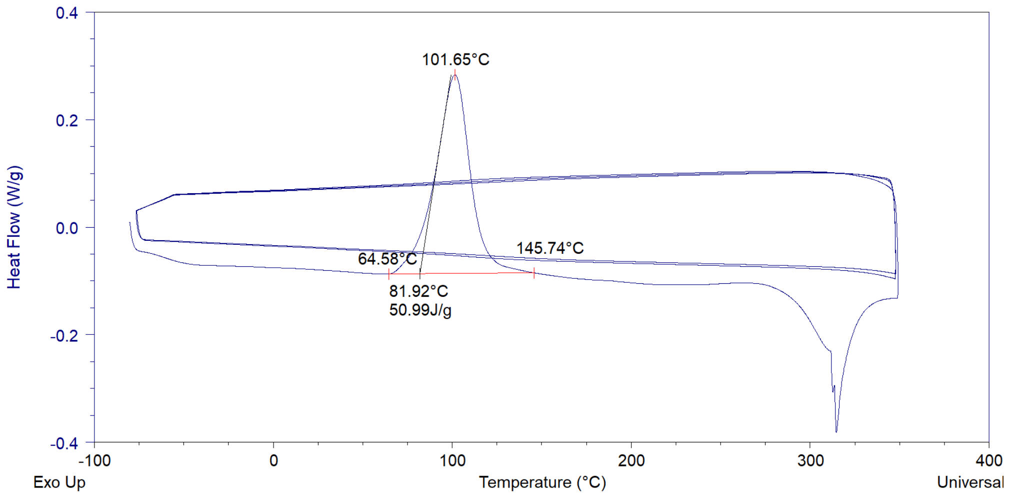
2. **Mechanical behaviour**
    1. Dynamic Mechanical Analysis (DMA)
    2. Double Cantilever Beam (DCB)

3. **Scanning Electron Microscope (SEM)**

1. Process development

DSC

- To detect physical transformations of samples
  - → Cross-linking temperature
  - → Chemical kinetic



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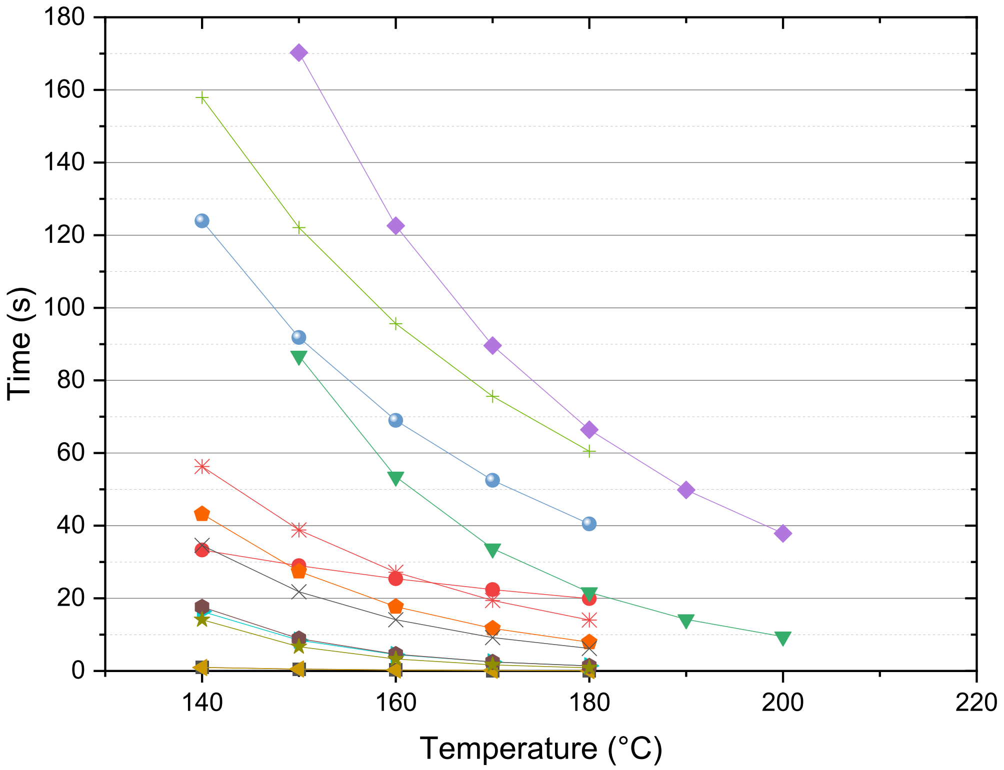


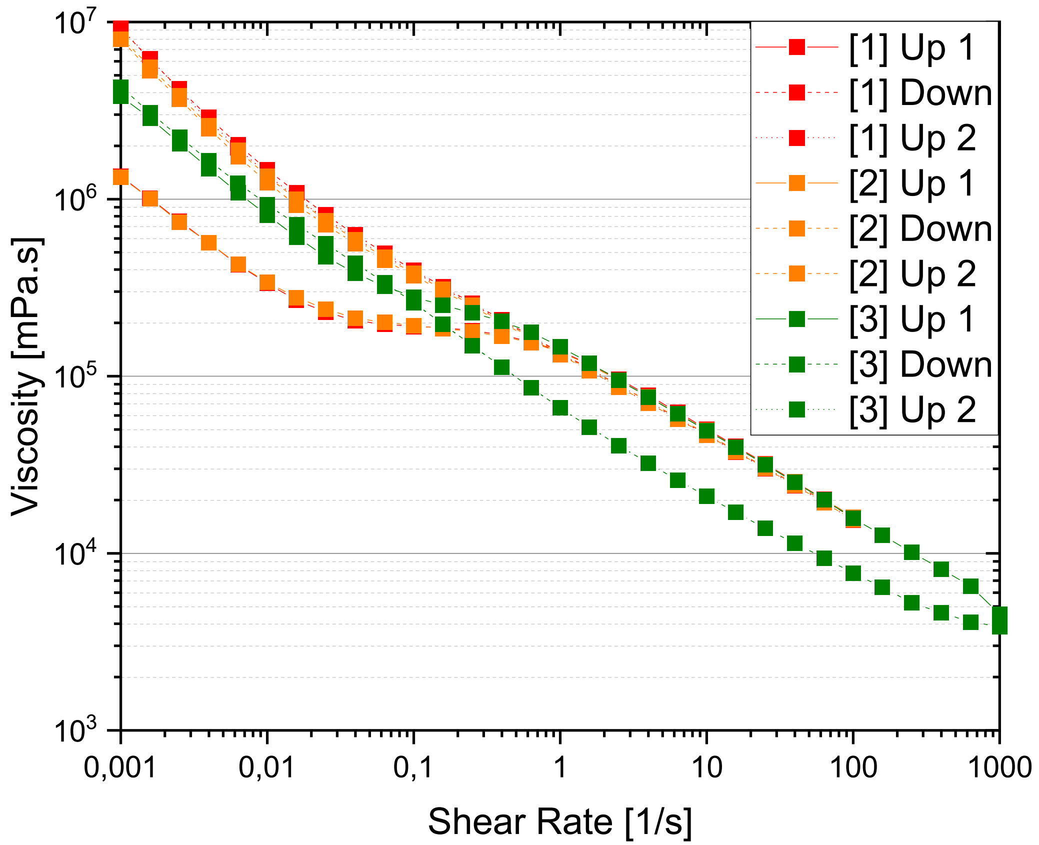
- Large variety of crosslinking behaviour:
  - Ultra fast cross-linking at usual curing temperature
  - Time up to 60 s to complete crosslinking at 180°C

- Two differents processes to deal with:
  - BB ECA: need to be fast with a weak ribbons-ECA interface
  - Shingle: could take more time with strong Si-ECA interface

- Some ECAs with possible compatibility with tandem PK process

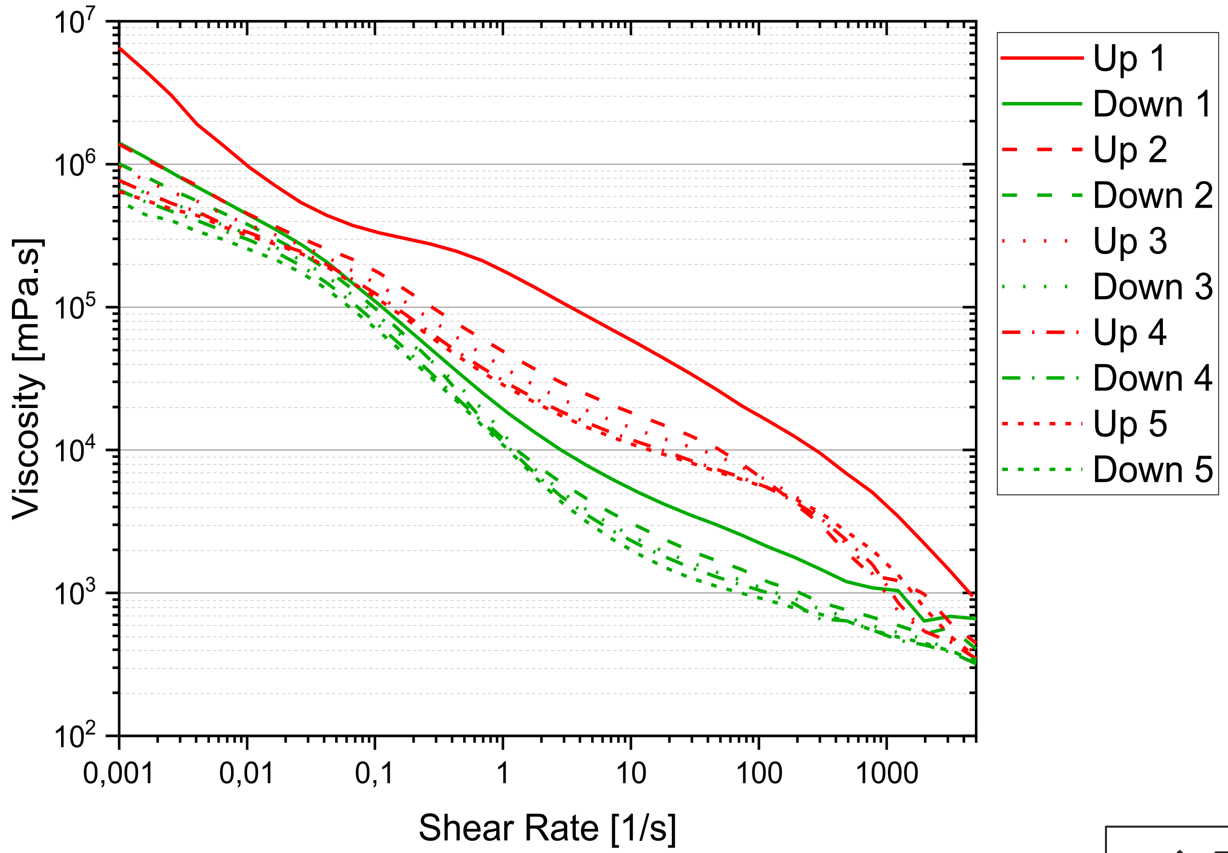
→ Evaluate ECA curing time process

Rheological behaviour



- Rheofluidifying material
  - Decrease of viscosity with increase of shear rate
  - Non-newtonian behaviour
- Critical shear test value: 650 s^{-1}:
  - Decrease of the viscosity
- Going further:
  - $\dot{\gamma} = \frac{v_p}{T}$ with v_p = 300mm/s and T=60µm
  - **Shear rate can reach 5000s^{-1} in stringer**

Rheological behaviour

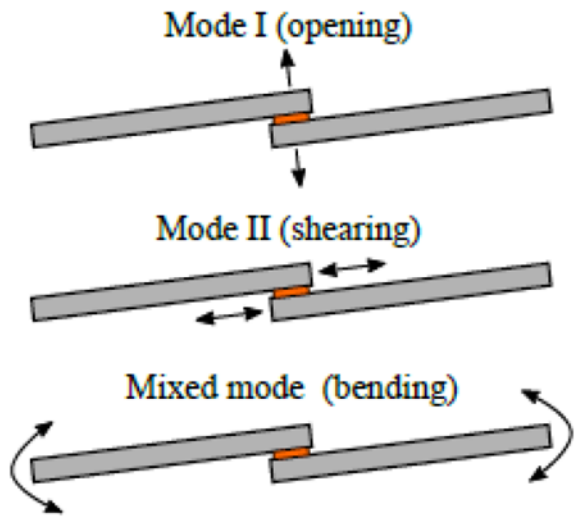


- Decrease of viscosity before stabilization
  - Cycle 1 shows the highest viscosity
  - Stabilization around cycle 3/4
- Irregular behaviour at high shear rate
- Could lead to higher mass deposition during production day

→ Evaluate ECA deposition process during production day

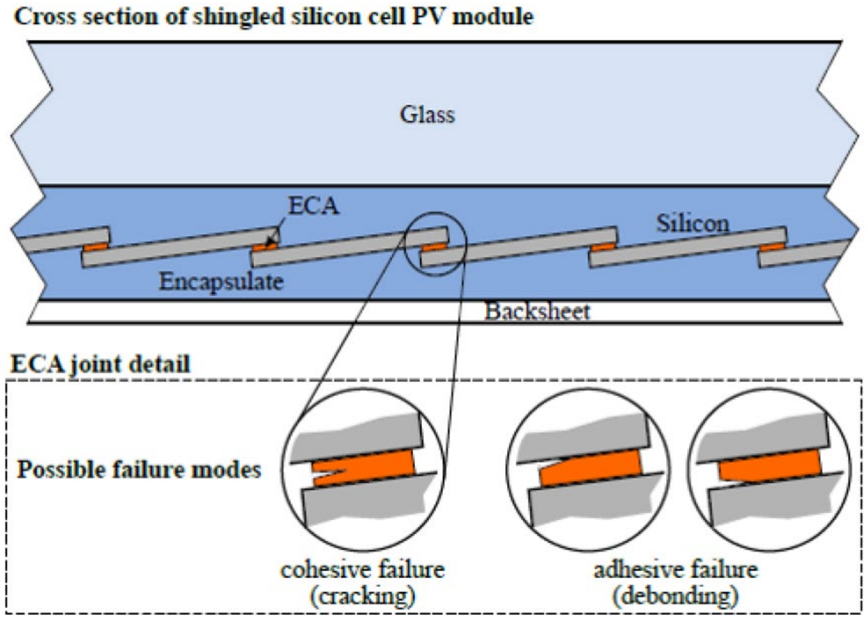
2. Mechanical characterization

Some theory



From [1] **Fracture modes**

- Materials can be subjected to 3 possible fracture mode:
  - Opening (I)
  - Shearing (II)
  - Bending (III)
- Fracture propagation is allowed by the elastic energy already stored in the system



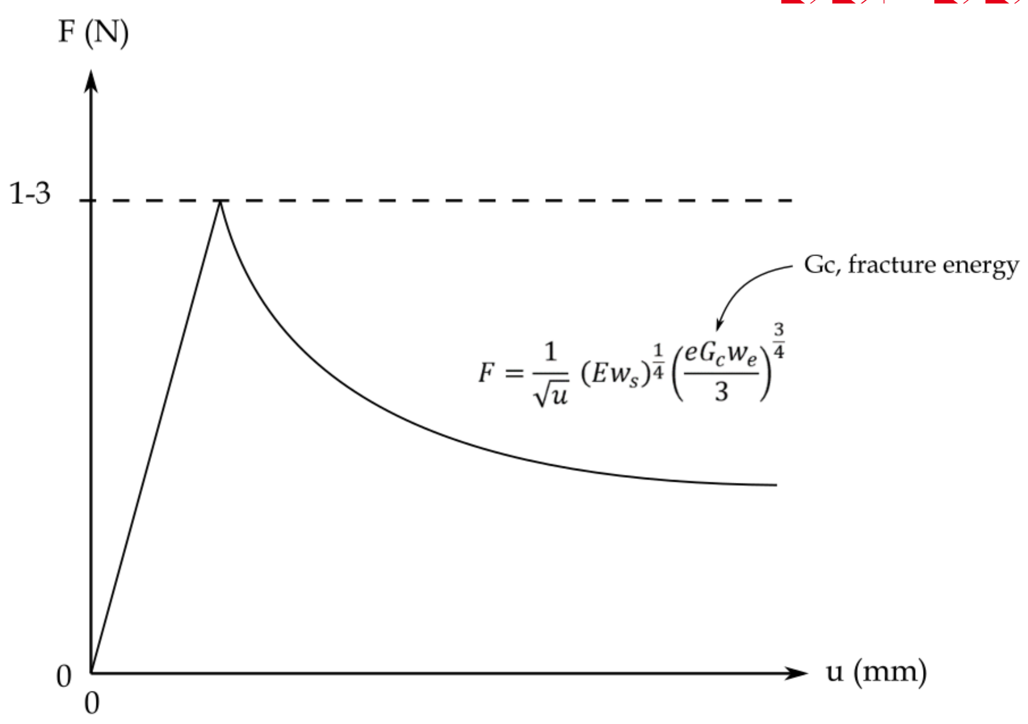
From [1]

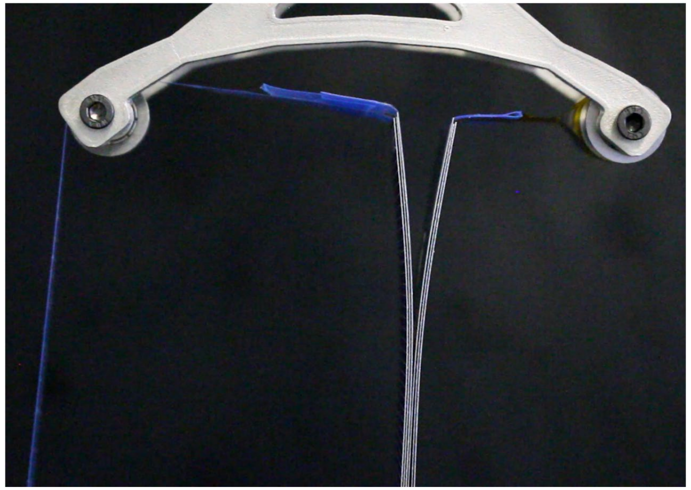
- Focus on mode I:
  - the weakest mode
  - is likely to occur for the shingle interconnection
- How to characterize:
  - type of failure
  - critical energy release rate

[1] M. Springer and N. Bosco, 'Linear viscoelastic characterization of electrically conductive adhesives used as interconnect in photovoltaic modules', *Progress in Photovoltaics: Research and Applications*, vol. 28, no. 7, pp. 659–681, 2020, doi: 10.1002/pip.3257.

DCB theory

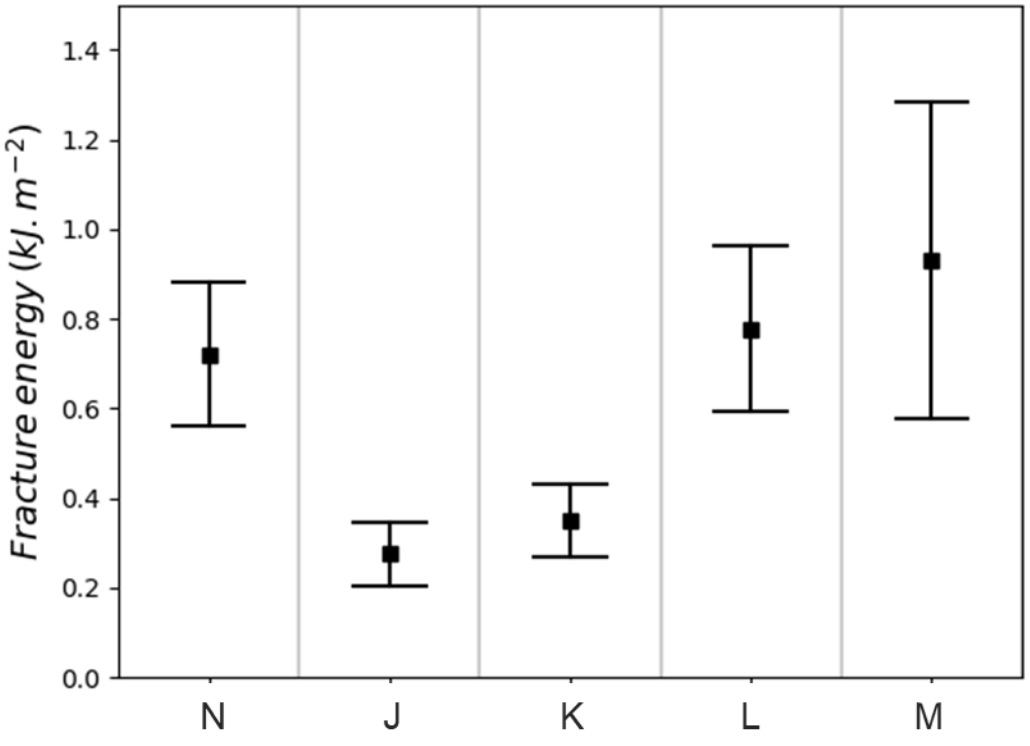
- Failure behaviour of the ECA
- Mechanical response
  - First a loading regime ($F \propto u$)
  - Second an opening regime ($F \propto 1/\sqrt{u}$)
    - Pre-factor depends on geometrical features (& cells stiffness)
- Fracture energy $\boldsymbol{G_c}$ depends on fracture type





Sketch of the expected mechanical response in DCB

DCB – comparative results

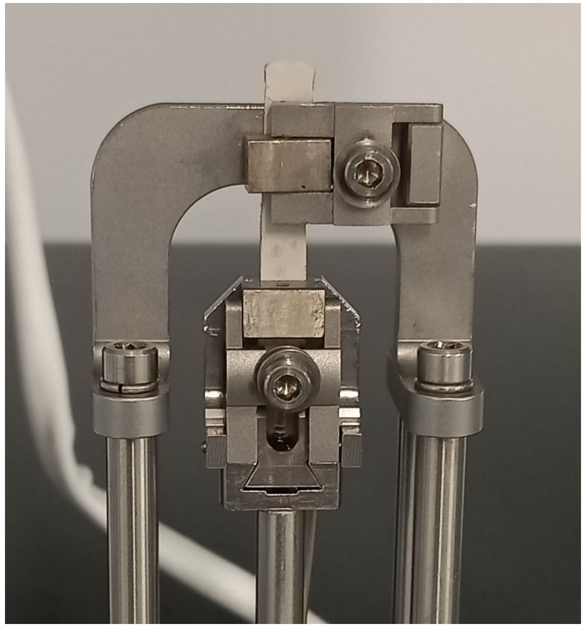


- Typical values for polymer adhesives
- ECAs failures are cohesive (no bonding issues)
- N, L & M have the highest fracture energy (cohesive fracture)
- J & K failure energies are quite small

→ Fracture energy evaluation
To be compared with module reliability

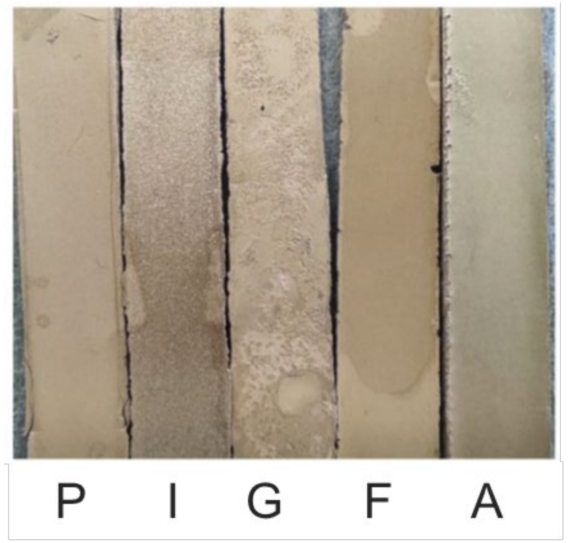
DMA

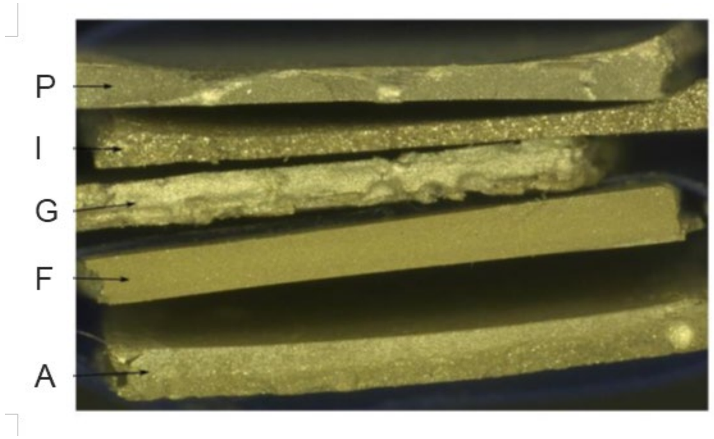
- Viscoelastic behaviour of the ECA



Sample manufacturing Process

- Polymerization of ECAs in a rectangular mold
- ECAs poured into molds at ambient temperature
- Production of 4-8 samples per ECA type





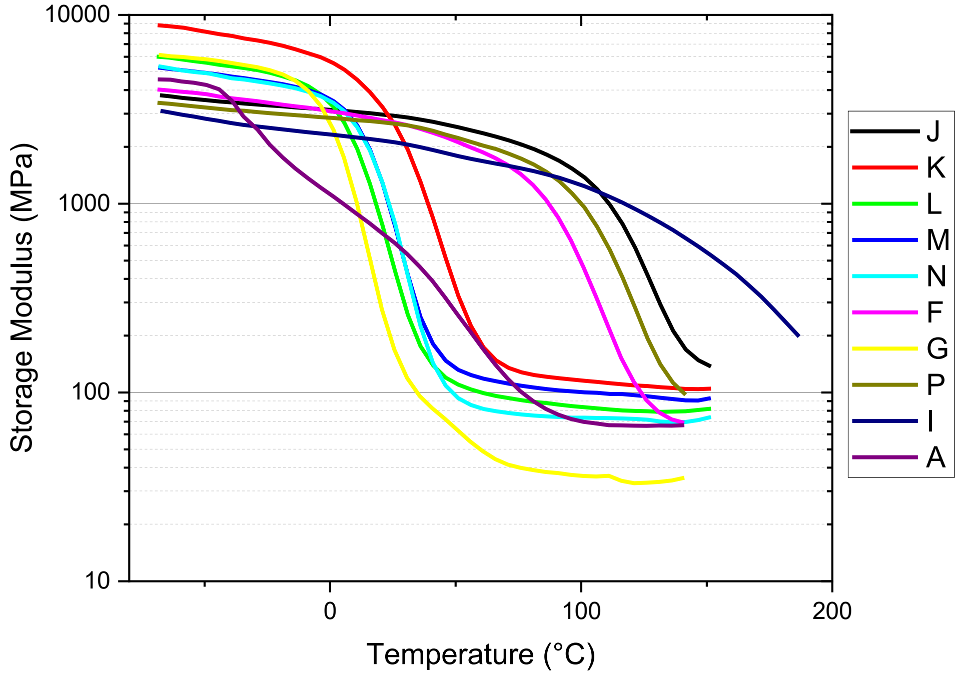
Sample aspect (after selection):

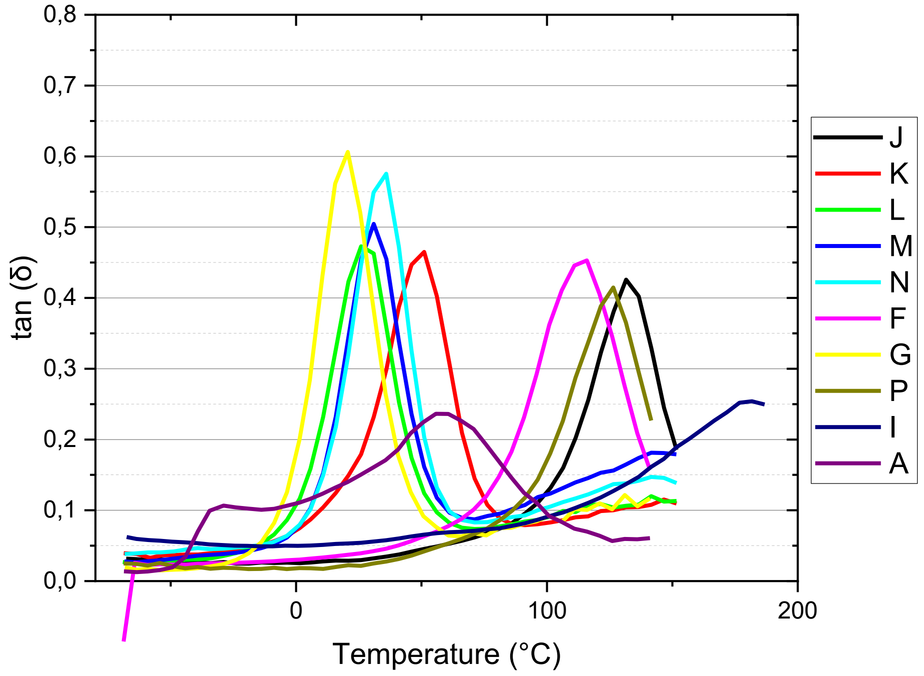
- Some surface roughness
- No macro-porosity issue

Testing mode: <u>Tension film</u>

- Frequency-Temperature sweep

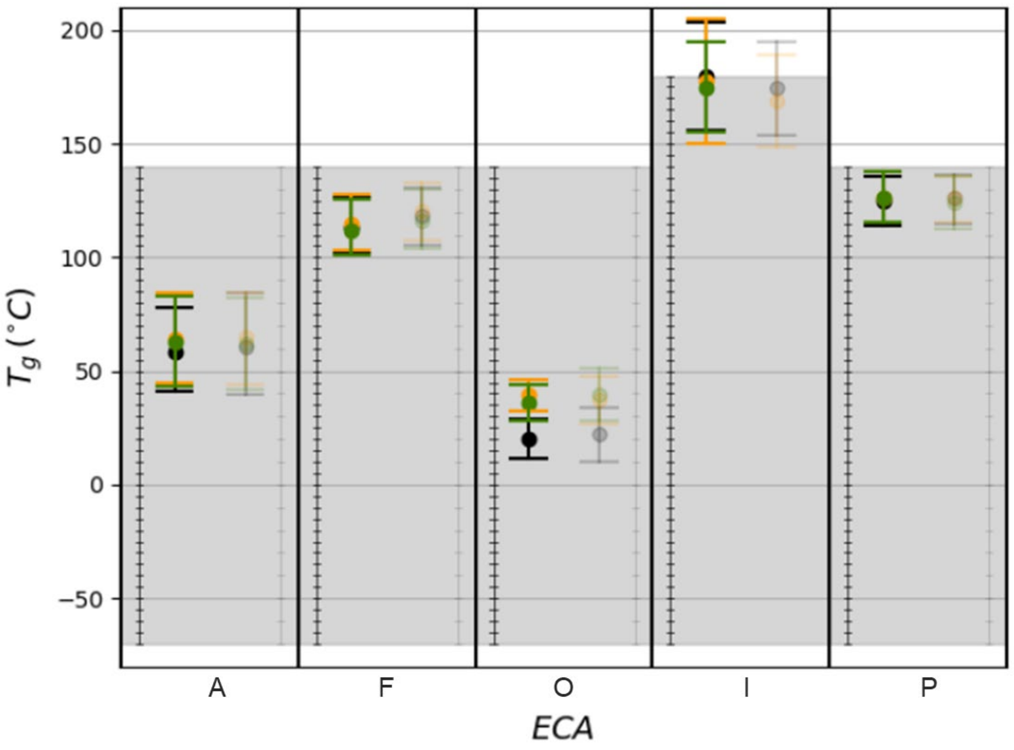
DMA





- Similar behaviour at low temperature with storage modulus ~ 4GPa
- Variety of behaviour between ECA but two groups could be identified
  - Group 1 with Tg between 20 and 50°C and a stable behaviour at high temperature
  - Group 2 with Tg above 100°C and no stable behaviour at high temperature
- ECA **A** and **I** show different behaviour among all other ECA

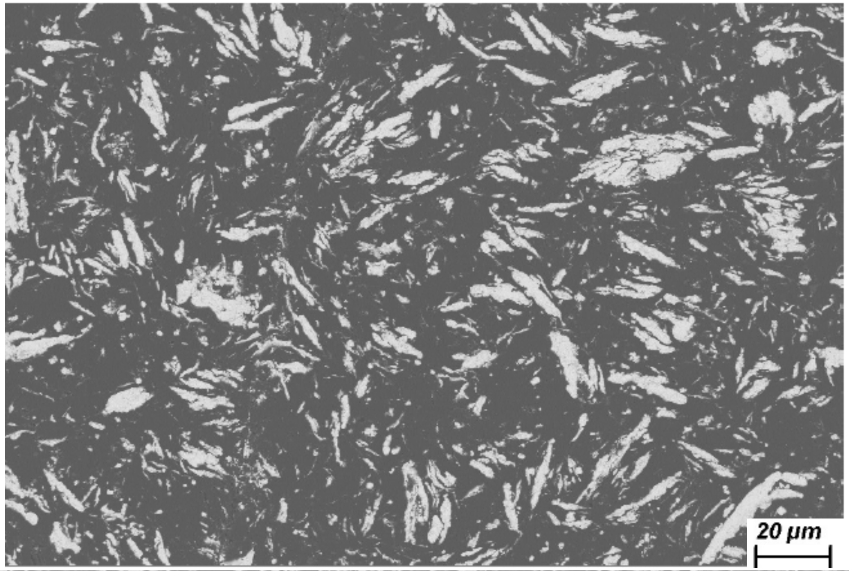
DMA



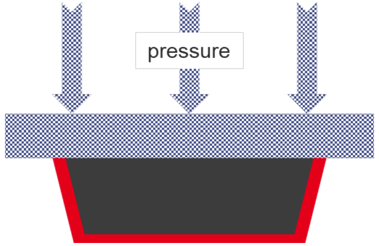
- Some DMA samples were submitted to thermal cycling test (with standard amplitude and high amplitude)
- 4 samples show no change at all
- One ECA shows Tg change after TC (mechanism under investigation)

3. Scanning Electron Microscopy

SEM



ECA crosslinked without constraints



ECA crosslinked with constraints

- SEM shows the importance to process correctly the ECA to have a percolation way through it
- To be done: effect of Thermal Cycling and CTE mismatch between resin and conductive particle

Conclusion

- **ECA, as composite material, is a very broad material family**

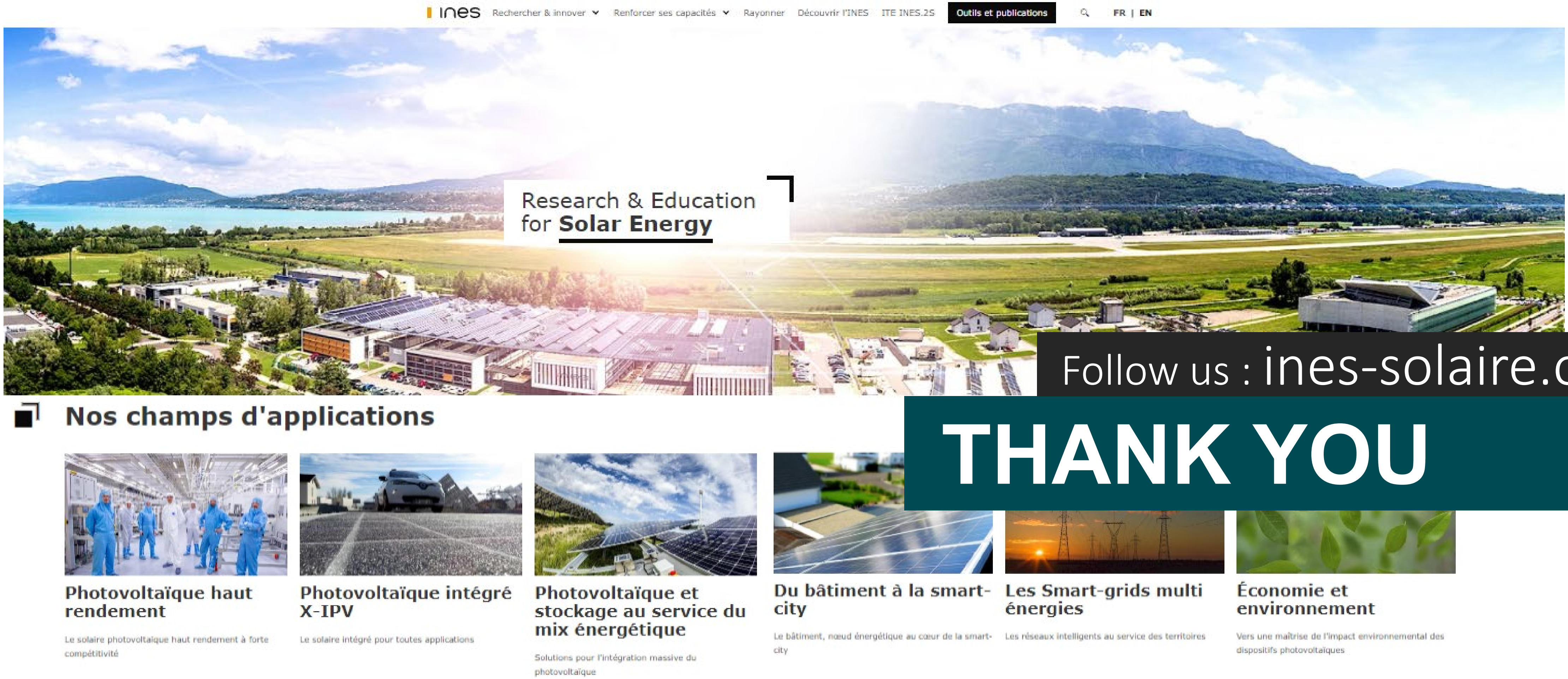
- **Proper assessment of process characterization is important:**
  - Cross-linking temperature and kinetics for curing process ➔ ***DSC***
  - Rheological behaviour for « Screen-printing » or dispense process ➔ ***Rheology***

- **Mechanical behaviour**
  - Understand viscoelastic behaviour and failure behaviour ➔ ***DCB + DMA***
  - Further understanding of ageing effect

- **Microscopy to visualize ECA organization** ➔ ***SEM***

To go further

- **Complete characterization for all ECA**
- **Assess behaviour before/after ageing (TC / DH / HF)**
- **Link the behaviour to module performance and reliability/durability**



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